Advanced Thermal Technologies for Space Science Missions at JPL

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January 31, 2000; Gaj Birur

OUTLINE

- Future Space Science Missions at JPL
- Thermal Control Requirements of Future JPL Missions
- Advanced Thermal Control Technologies Needed
- Thermal Technology Development JPL
- Conclusions

Future Space Science Missions at JPL

- Mars missions - landers, rovers, in-situ production experiments, and robotic support for human colonization missions, Mars Micro Missions
- Missions to comets/asteroids - e.g., Comet Nucleus sample return Mission, comet exploration and sample return
- Missions to other Planets - Europa orbiter/lander, Saturn Ring Observer, Neptune orbiter
- Other Missions - Earth orbiting spacecraft/science payload, space telescopes, instruments
- Microspacecraft Missions

Future Advanced Thermal Technology Needs

- **Temperature control applications**
  - Planetary orbiters and landers; earth orbiting instruments; sample return missions
- **Survival heater power reduction applications**
  - Mars lander and rovers, earth orbiters
- **Precision temperature control for large structures**
  - Antennas, optical benches, inflatables; milli K level modeling
- **Universal spacecraft thermal architecture**
  - Applicable to inner planet, outer planet, and earth orbiting missions
- **Microspacecraft thermal control**
  - Multifunctional structures, miniature hardware, **MEMS based thermal technologies for Micro/Nano Sciencecraft**

Temperature Control Applications

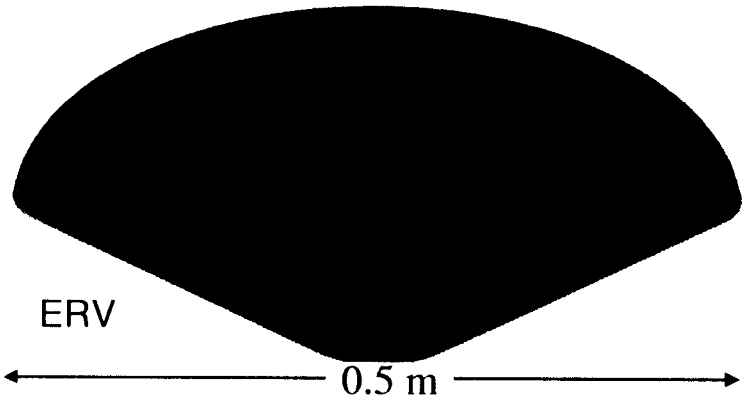
- **Maintain temperature sensitive equipment such as electronics, battery, and instrument within their allowable temperature limits**
  - Electronics in the -20 to 50 C operating range and -40 to 70 C Non operating range
  - Batteries in the -20 to 30 C range (both op and non-op mode)
  - The requirements for sensors can range from -150 to 40 C range
  - Science instrument requirements range from -50 to 40 C range
  - Returning samples from comets and planets need -180 C through sample recovery on earth
  - Rovers mechanical hardware on planetary surface above - 60 C

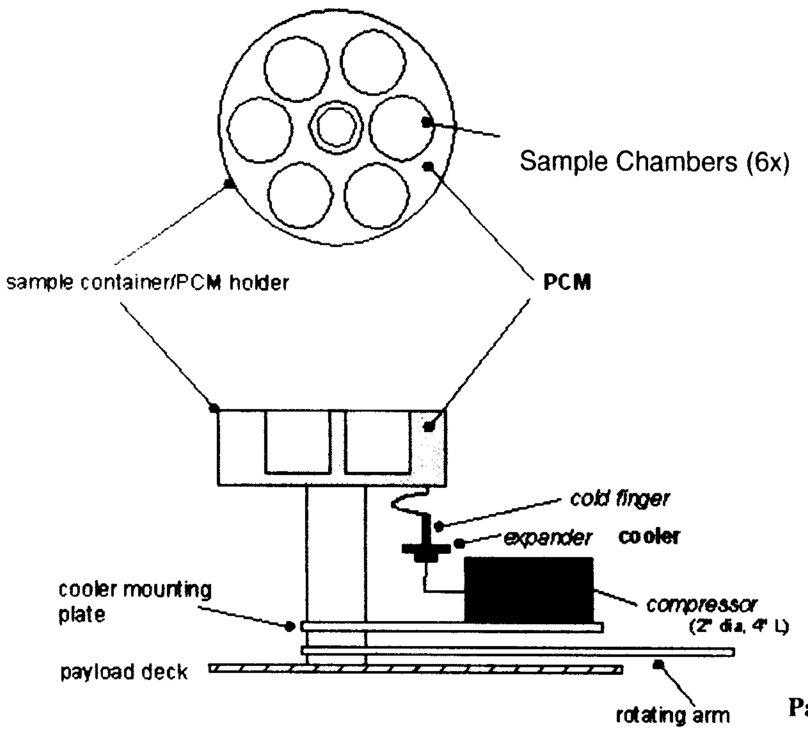
- **Typical thermal technologies needed for these applications are:**
  - For heat removal/rejection - High thermal conductivity materials, high heat transport devices such as heat pipes, mechanically pumped cooling loops, low a/e passive coatings
  - For conserving heat - High performance lightweight insulation, phase change thermal storage, heat switches, variable emissivity coatings
  - For meeting low temperature needs - Passive and active coolers

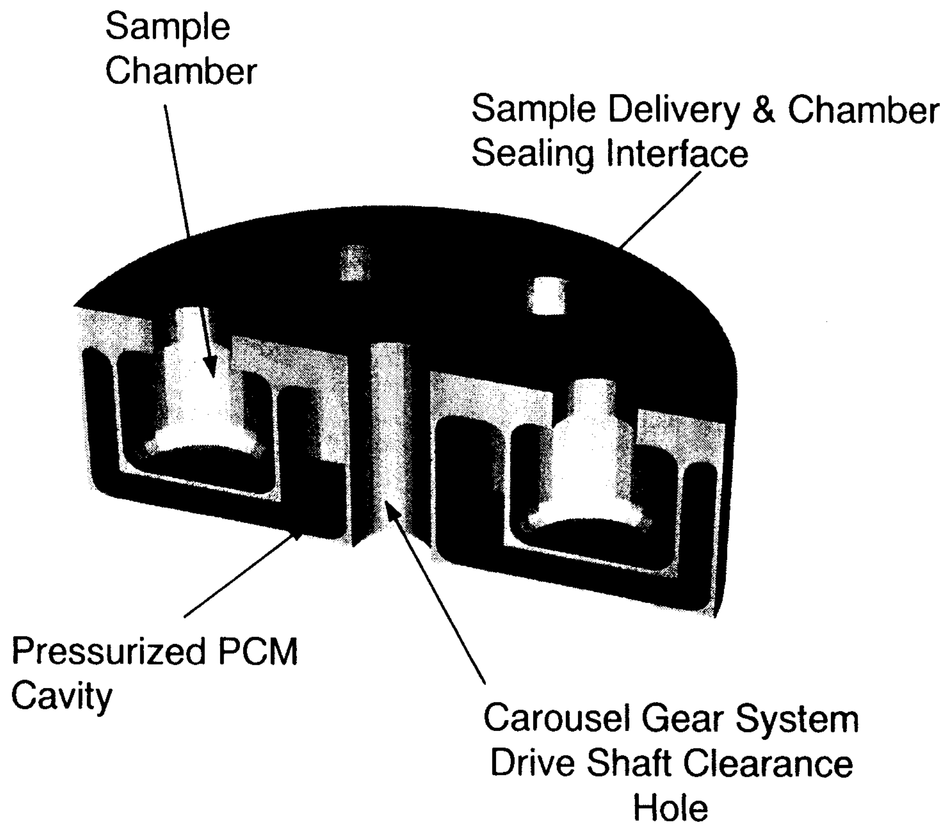
Temperature Control Applications

Comet Nucleus Sample Return

Cryogenic Maintenance - Sample Container Concept







Temperature Control Applications

Phase Change Thermal Storage for Battery applications

Description:
- Phase change material (PCM) utilizes latent heat to protect batteries against low temp. extremes by providing thermal storage
- PCM stores excess heat when available and releases the heat when needed
- The technology is simple, reliable, and mass efficient

Current Status:
- Dodecane PCM material (-10 C MP) encapsulated in a carbon fiber matrix
- A battery/PCM capsule was fabricated by ESLI for JPL
- It is integrated with miniature LHP and being tested at JPL in a simulated Martian environment to evaluate rover battery/electronics thermal control

Future Development:
- Investigate PCM materials with lower MP for lower temperature operations (below -20 C)
- Develop and qualify low mass system for thermal energy management on Mars landers, in-situ experiments and Microspacecraft missions

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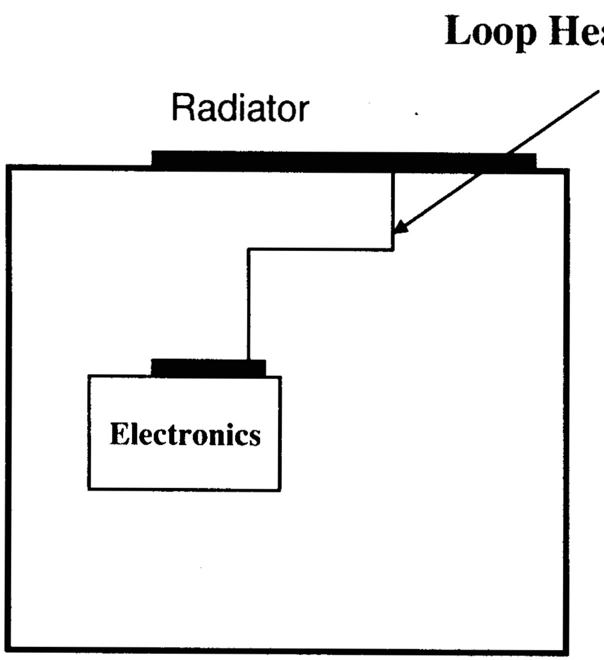
Survival Heater Power Reduction Applications

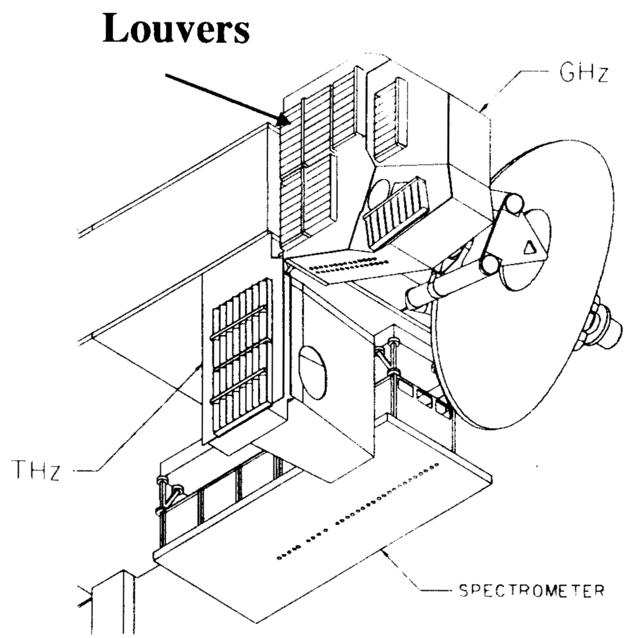
- **A key design driver for earth orbiting and planetary spacecraft and planetary landers and rovers**
  - Earth orbiting spacecraft during safe survival mode
  - Mars landers and rovers during Martian nights (temperature drop to -100 C)
  - Cometary missions during sample collection periods (temperature as low as -180 C)
  - Deep space scince spacecraft safe mode

- **Typical thermal technologies needed for these applications are:**
  - Thermal conductance modulation -Mechanical heat switches, variable conductance heat pipes, loop heat pipes, mechanically pumped cooling loops
  - Radiative heat rejection modulation - Variable emissivity devices, deployable radiators
  - Heat conservation - High performance lightweight insulation, thermal storage

Survival Heater Power Reduction Applications

Examples for TES and MLS Instruments





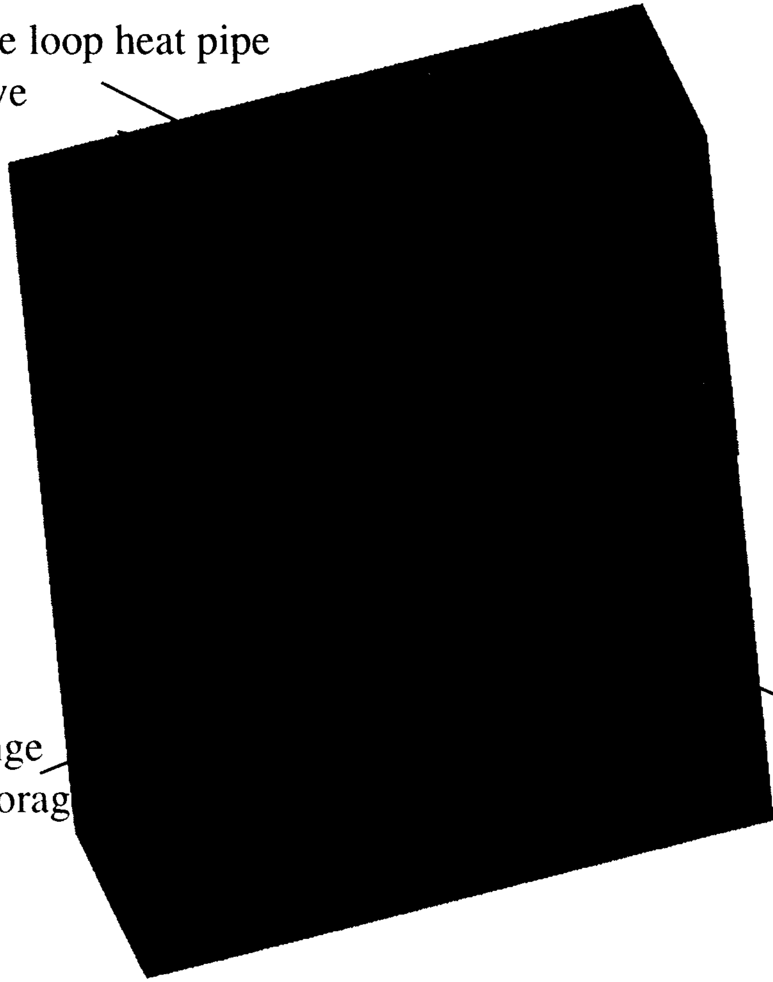
TES Instrument

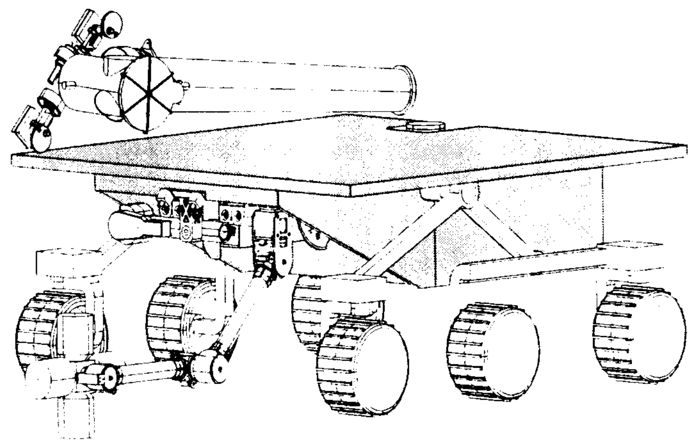
MLS Instrument

Survival Heater Power Reduction Applications

Mars Rover Thermal Control Design

Miniature loop heat pipe
with valve





Phase Change
Thermal Storag
Capsule

Lightweight high
performance Aerogel
Insulation enclosure

Initial testing at JPL to be completed by April 2000

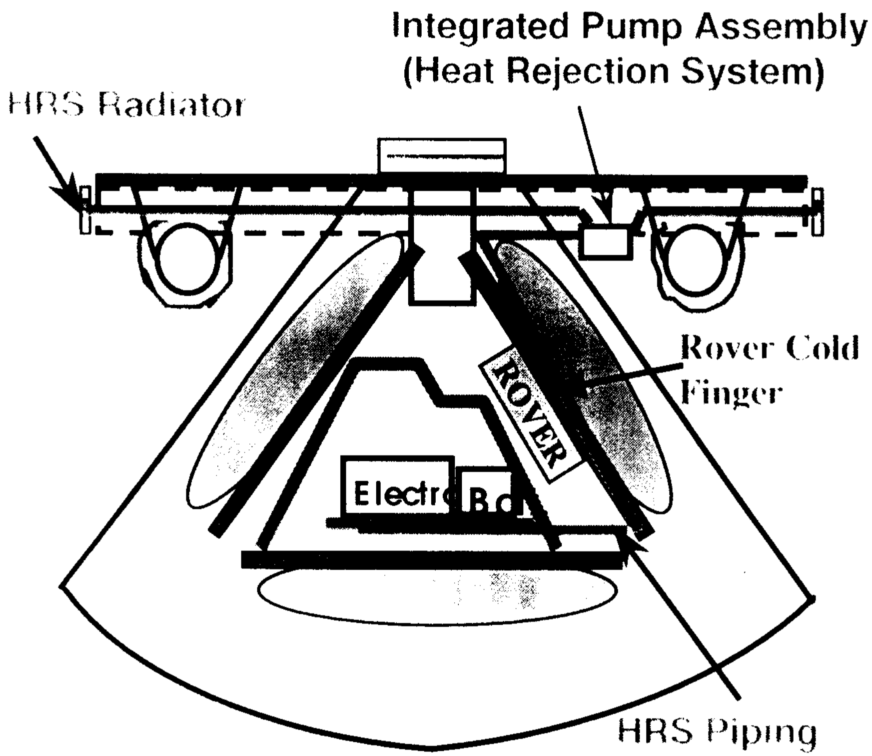
Precision Temperature Control of Structures

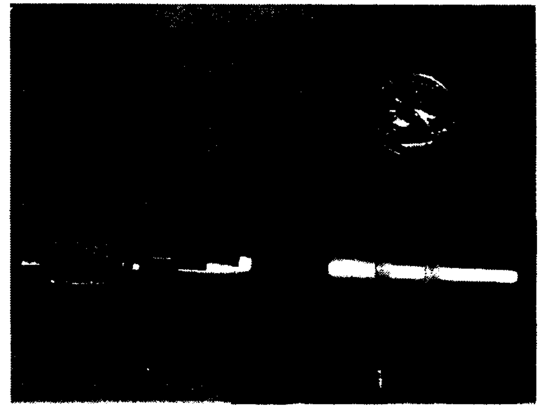
- **Large demand for precision control of structures (both large and small) on future spacecraft**
  - Optical benches on earth orbiting and deep space science instruments
  - Large antennas, telescopes, interferometric platforms,
  - Mars landers and rovers during Martian nights
  - Cometary missions during sample collection periods

- **Typical thermal technologies needed for these applications are:**
  - Thermal conductance modulation - mechanical heat switches, active cooling loops, variable conductance heat pipes, loop heat pipes
  - Radiative heat rejection modulation - Variable emissivity devices, deployable radiators,
  - Heat conservation - High performance lightweight insulation, thermal storage
  - Double precision thermal modeling

Precision Temperature Control of Structures

Mars Pathfinder Mechanically Pumped Cooling Loop

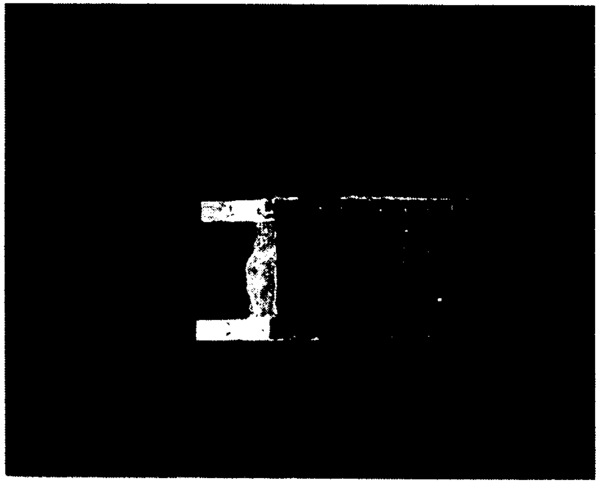




- **Electronic equipment shelf maintained within +/- 2 C for entire cruise**

Precision Temperature Control of Structures

Variable Emissivity Surfaces (Electrochromic)



Electrochromic device from Ashwin-Ushas

Description

- A change of surface emissivity in the range of 0.3 to 0.8 by an external electric field of < 5V
- Provides a low mass device to vary heat rejection capacity on the spacecraft
- Conducting polymer material used as electrochromic material
- Devices based on similar materials used for auto and building energy conservation

Status & Future Applications

- Significant work by EIC labs, LBL Berkeley, ASHWIN-USHAS, NASA Lewis
- JPL, GSFC & AFRL investigating for S/C use
- Excellent candidate for JPL's Integrated Thermal Energy Management (ITEM) systems for future spacecraft
- Initial validations tests: 10 Mrad Gamma radiation
- Space qualification of the material is an important next step;
  - Thermal vac and radiation tests at JPL
  - Solar wind tests at GSFC
- Device failure mechanisms in space applications need to be understood

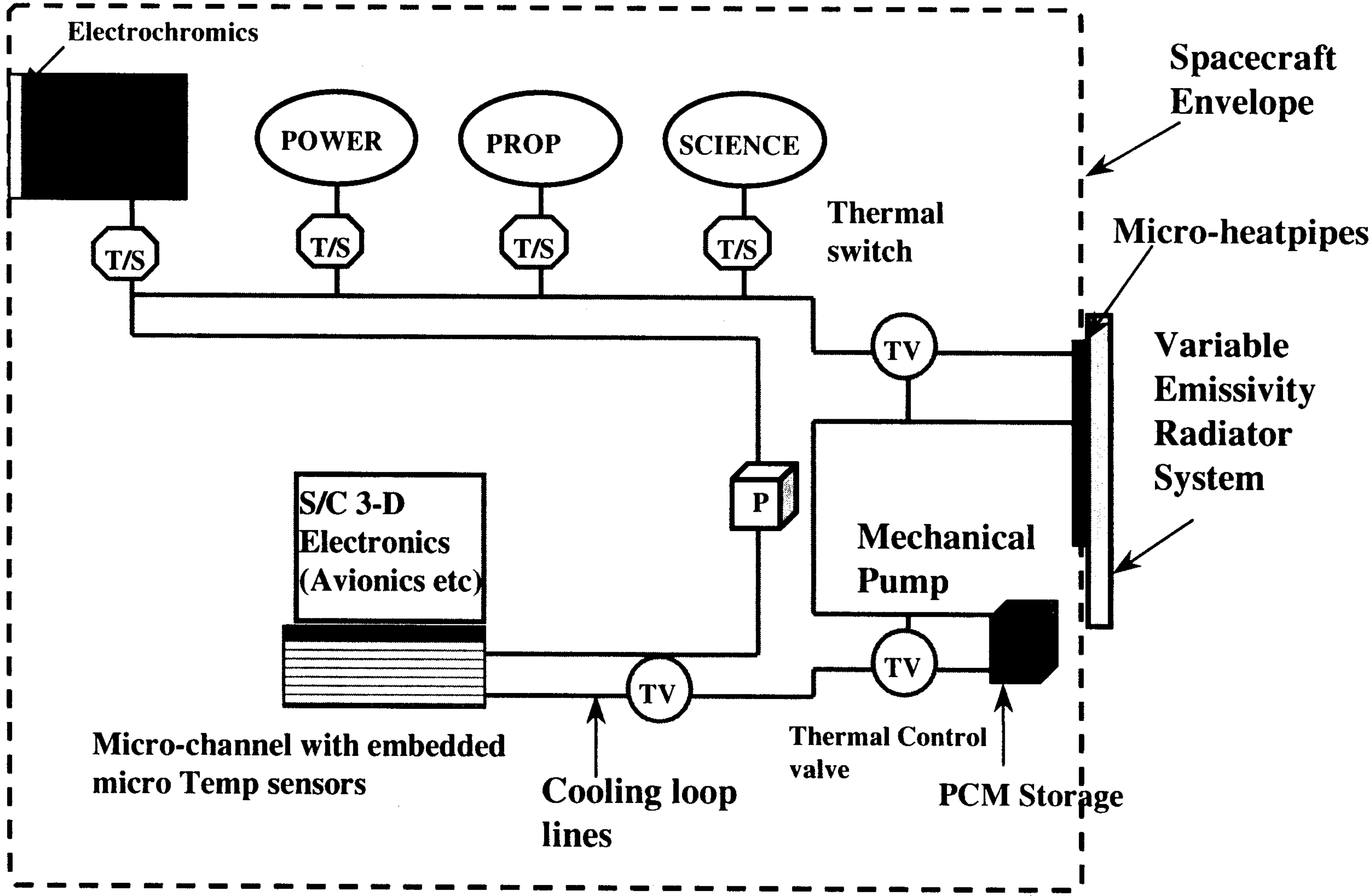
JPL Universal Spacecraft Thermal Control Architecture

- **Need for a robust flexible thermal architecture for use on wide variety of future space science missions**
  - Missions to inner planets with hot environment
  - Outer planet missions operating in cold environment
  - Planetary landers and rovers
  - Comet and planet sample return missions
  - Spacecraft missions with changing configurations and power densities
  - Based on integrated thermal energy management (ITEM)

- **Benefits of this architecture include:**
  - Shorter design, build, and launch cycles
  - Low survival heating power requirement
  - Better temperature control of equipment and instruments

Universal Spacecraft Thermal Control Architecture

Thermal Control Architecture Based on Energy Management

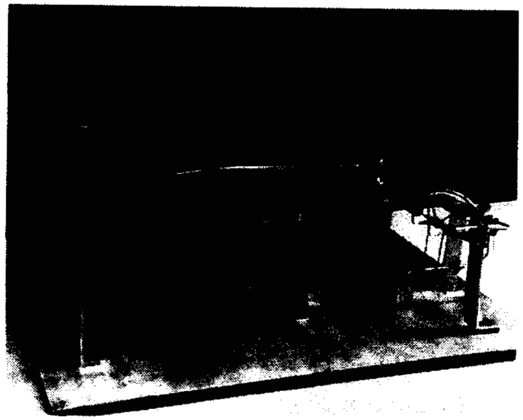


Micro/Nano Spacecraft Thermal Control Technologies

- **Future micro/nano spacecraft with physical sizes of less than 0.5 m and power levels (~ 50 W) will require new advanced thermal technologies**
- **Mission examples:**
  - Missions to inner planets with hot environment
  - Outer planet missions operating in cold environment
  - Planetary landers and rovers
  - Comet and planet sample return missions
  - Spacecraft missions with changing configurations and power densities

- Multifunctional Structures
- Miniature heat switches
- Miniature thermal control valves
- Miniature louvers
- Miniature heat pipes
- Miniature mechanical pumps
- MEMS based thermal control technologies

Micro/Nano Spacecraft Thermal Control Technologies
Miniature Loop Heat Pipe Technology



- Miniature loop heat pipe (Dynatherm Corporation)

Technical Description

- A versatile thermal control device: transfers heat, controls source temperature, and acts as a heat switch(all in one)
- Light weight (less than 150 gms) device compared to other thermal control hardware performing the same function
- Enormous flexibility in locating heat sources and sinks on the spacecraft

Participants & Facilities

- JPL is investigating this technology for space applications (Mars rover/lander, micro S/C
- Tests to be performed at JPL and Goddard during FY00 for evaluating miniature multiple evaporator loop heat pipe
- Dynatherm Corporation has designed and fabricated a miniature loop heat pipe for Mars Rover battery thermal control concept

Mission Impact & Future Applications

- This technology reduces S/C thermal control mass and provides enormous flexibility
- This is a key technology for enabling Thermal Energy Management System for DSST 2nd Delivery
- This technology is applicable to small & large S/C and planetary vehicles thermal control

Micro/Nano Spacecraft Thermal Control Technologies

JPL Miniature Loop Heat Pipe Test Bed

Micro/Nano Spacecraft Thermal Control Technologies

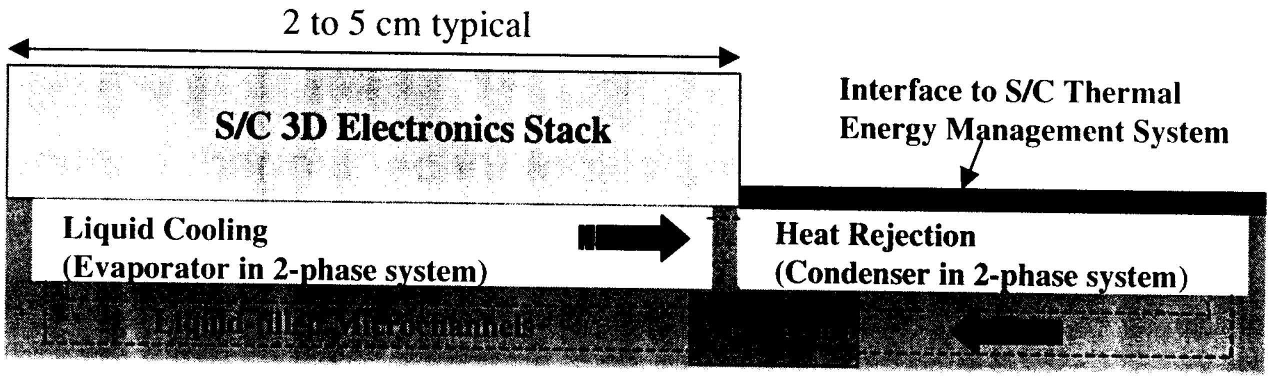
MEMS based Thermal Technologies for Micro/Nano Sciencecraft

- **Shrinking size of future spacecraft is leading to the use of Micro-Electro-Mechanical Systems (MEMS) on future spacecraft**
  - Compact avionics and electronics with high power densities
  - compact sensors and instruments requiring demanding thermal control
  - Compact high power lasers for optical communications
  - System-On-A-Chip sciencecraft with high power densities

- **Thermal technologies needed for these missions are**
  - Microchannels based single and two-phase cooling systems
  - Micropumps for circulating cooling liquids
  - Variable emissivity radiators to modulate heat rejection
  - MEMS based thermal switches and valves

Micro/Nano Spacecraft Thermal Control Technologies

MEMS Based Microchannel liquid pumped cooling



Technical Description

- MEMS-based cooling system for high power density compact microelectronics and science payloads. Over 25 W/ cm^2
- Microchannels integrated with the payload and a micropump pumps the cooling liquid
- Micropump technologies such as electro-kinetic and piezo-electric pumps will be investigated.

Technical Challenges

- Microchannel fabrication; especially complicated flow paths, integration of appropriate micropump with the microchannels
- Developing a micropump system that meets the required hydraulic performance

Team Members

- JPL, Goddard Space Flight Center, Stanford University

Presenter's Introduction

- Tim O'Donnell -
  - Tim is the Manager of Thermal and Propulsion Engineering Section at JPL where he has been working for the last 25 years. He has worked on materials technologies related earth orbiting and deep space missions.
- Gaj Birur -
  - Gaj is a Senior Engineer in the Thermal and Propulsion Engineering Section at JPL where he has been working for the last twenty years. His current areas of interest are spacecraft thermal control design, thermal hardware implementation, and advanced thermal control technologies for future interplanetary spacecraft and Mars landers and rovers.